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LIMITS OF BEACH AND DUNE EROSION IN RESPONSE TO WAVE RUNUP ELUCIDATED FROM SUPERTANK

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Abstract: The unique dataset from SUPERTANK is analyzed to examine the upper limit of beach change in response to elevated water level caused by wave runup. Thirty SUPERTANK runs are investigated, including both erosional and accretionary wave conditions under random and monochromatic waves. The upper limit of beach change approximately equals the maximum vertical excursion of swash runup. Exceptions to this direct relationship are those with beach or dune scarps. The vertical extent of wave runup above mean water level on a non-scarped beach is approximately equal to the significant breaking wave height. Scarps substantially limit the uprush of swash motion, resulting in a much reduced maximum runup. Predictions of wave runup are not improved by including a slope-dependent surf-similarity parameter. The limit of wave runup is substantially less for monochromatic waves than for random waves, attributed to absence of low-frequency motion for monochromatic waves.

INTRODUCTION

Quantification of wave runup and its relationship to the upper limit of beach-profile change are required for understanding and predicting beach and dune erosion, especially during storms. Wave runup is composed of wave setup, defined as a super-elevation of the mean water level, and swash runup, or fluctuations about that mean (Holman and Sallenger 1985; Nielsen 1988; Yamamoto et al. 1994; Holland et al. 1995). Numerous studies on the limits of wave runup have been conducted, resulting in the development of several predictive models, from three approaches.

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The earliest physics-based approach is developed upon a theoretical derivation for monochromatic waves. Bowen et al. (1968) derived a wave setup slope inside the surf zone for monochromatic (sinusoidal) waves as:

$$\frac{\partial \overline{\eta}}{\partial x} = -K\frac{\partial h}{\partial x} \qquad K = (1 + 2.67\gamma^{-2})^{-1} \tag{1}$$

where h = still-water depth, $\overline{\eta}$ = wave setup, x = cross-shore coordinate, $\gamma = H/(\overline{\eta} + h)$ and H = wave height. Based on both theory and laboratory measurements, the maximum set-up under a monochromatic wave, $\overline{\eta_M}$, was found to occur at the shoreline:

$$\frac{\overline{\eta_M}}{H_b} = 0.3\gamma \tag{2}$$

where H_b = breaking wave height (Battjes 1974). The above equations concern only the wave setup portion of the runup.

The second approach is based mainly on field measurements made on dissipative beaches. Guza and Thornton (1981) suggested that the setup at the shoreline, $\overline{\eta_{sl}}$, is linearly proportional to the significant deepwater wave height H_o:

$$\overline{\eta_{sl}} = 0.17H_o \tag{3}$$

In a following study, Guza and Thornton (1982) found that the significant wave runup, R_s, (including both wave setup and swash runup) is also linearly proportional to the significant deepwater wave height:

$$R_s = 3.48 + 0.71H_o \qquad \text{(units of centimeters)} \tag{4}$$

Comparing Eqs. (3) and (4), the entire wave runup is approximately 4 times the wave setup, i.e., swash runup constitutes a significant portion of the total elevated water level. According to Huntley et al. (1993), Eq.(4) is the best choice for predicting wave runup on dissipative beaches. Based on field measurements on highly dissipative beaches, Ruessink et al (1998) and Ruggiero (2004) also found linear relationships, but with different empirical coefficients.

The third and more recent approach, proposed by Holman (1986) and several similar studies (Holman and Sallenger 1985; Ruggiero et al. 2004; Stockdon et al. 2006), argued that more accurate predictions can be obtained by including the surf similarity parameter, ξ:

$$\xi = \frac{\beta}{(H_o / L_o)^{1/2}} \tag{5}$$

where L_o is the deepwater wavelength, and β is the beach slope. Holman (1986) found a dependence of the 2% exceedence of runup R_2 on the deepwater significant wave height and the surf similarity parameter:

$$R_2 = (0.83\xi_o + 0.2)H_o \tag{6}$$

Stockdon et al. (2006) expanded upon the Holman (1986) analysis and developed the empirical equation:

$$R_2 = 1.1\left(0.35\beta_f (H_o L_o)^{\frac{1}{2}} + \frac{\left[H_o L_o (0.563\beta_f^{\ 2} + 0.004)\right]^{\frac{1}{2}}}{2}\right) \qquad (7)$$

Realizing the variability of beach slope in terms of both definition and measurement, Stockdon et al. (2006) define the foreshore beach slope as the average slope over a region of two times the standard deviation of continuous water level record.

Most field studies were conducted on gentle sloping dissipative beach and found wave runup within the swash zone to be dominated by infragravity frequency components, or surf beat. Mechanisms for generating low-frequency motion at the shoreline include 1) obliquely incident wave groups (Gallagher 1971; Bowen and Guza 1978), 2) time-varying wave breaking (Symonds et al. 1982; List 1992), and 3) bound long wave generated by periodical variations of mean water level due to wave groupiness outside the surf zone (Longuet-Higgins and Stewart 1962). In contrast to numerous studies on wave runup, little data are available relating the limit of wave runup with that of the beach-profile change.

In this paper, data from the prototype-scale SUPERTANK experiment (Kraus et al 1992; Kraus and Smith 1994) are examined to study the limit of wave runup and corresponding limit of beach dune erosion. Specifically, this study examines 1) the level of swash run-up and wave setup; 2) time-series beach-profile changes under erosional and accretionary waves; 3) the relationship between the above two phenomena; and 4) the accuracy of existing wave runup prediction methods. A new empirical formula predicting the limits of wave runup and that of beach change is proposed based on the SUPERTANK data.

SUPERTANK EXPERIMENTS

One of the largest and most densely instrumented laboratory movable-bed studies to date is the SUPERTANK experiment. This multi-institutional effort sponsored by the Corps of Engineers was conducted at the O.H. Hinsdale Wave Research Laboratory at Oregon State University from July 29 to September 20, 1991 (Fig. 1). This facility is the largest wave channel in the United States that can contain a sandy beach through which experiments comparable to the magnitude of naturally occurring waves can be conducted (Kraus et al. 1992).

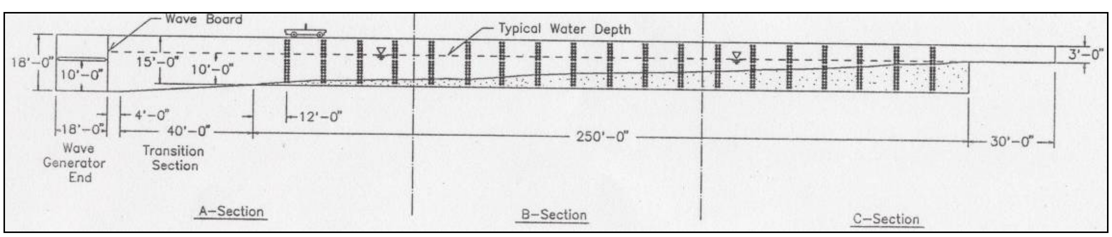

Fig. 1. Layout of SUPERTANK experiments. Dimensions are in feet and inches.

The SUPERTANK experiment measured total-channel hydrodynamics and sediment transport along with the resulting beach-profile changes. The wave channel was 104 m long, 3.7 m wide, and 4.6 m deep (the still water level was typically 1.5 m below the top) with a constructed sandy beach extending 76 m offshore (Fig. 1). The beach was composed of 600 m^3 of fine, well-sorted quartz sand with a median size of 0.22 mm and a fall speed of 3.3 cm/s. The wave generator and wave channel were equipped with a sensor to absorb the energy of reflected waves. The water-level fluctuations were measured with 16 resistance and 10 capacitance gauges. These 26 gauges, spaced 3.7 m apart, provided detailed wave propagation patterns, especially in the swash zone. The beach profile was surveyed following each wave run. The initial profile was constructed based on the equilibrium beach profile developed by Dean (1977) and Bruun (1954) as:

$$h(x) = Ax^{\frac{2}{3}} \tag{8}$$

where h = still-water depth, x = horizontal distance from the shoreline, and A = a shape parameter corresponding to a mean grain size of 0.30 mm. The initial beach was built steeper with a greater A-value to ensure adequate water depth in the offshore area (Wang and Kraus 2005). For efficiency, most SUPERTANK tests were initiated with the final profile of the previous run. Approximately 350 surveys were conducted using an auto-tracking, infrared Geodimeter targeting prism attached to a survey rod mounted on a carriage pushed by researchers. Although three lines, two along the wave-channel wall and one in the center, were surveyed, only the center line is examined in this study. Wave-processing procedures are discussed in Kraus and Smith (1994). To separate incident-band wave motion from low-frequency motion, a non-recursive, low-pass filter was applied. The period cutoff for the filter was set to twice the peak period of the incident waves.

After inspection of all 20 SUPERTANK tests, 5 tests with 30 wave runs were selected for analysis in the present study. The selection was based on the particular purpose of the wave run, the trend of net sediment transport, and measured beach change. Time-series beach-profile changes and cross-shore distribution of wave height and mean water level were analyzed. The breaker point is defined at the location with a sharp decrease in wave height (Wang et al. 2002). The maximum runup is defined by the location and beach elevation of the swash gauge that contained a value larger than zero wave height, i.e., water reached that particular gauge. There may be some differences in the runup measured in this study as compared to the video method (e.g., Holland et al. 1995) and horizontally elevated wires (e.g., Guza and Thornton 1982). The differences are not expected to be significant.

RESULTS AND DISCUSSION

The subject 30 wave runs are summarized in Table 1. The thirty cases are composed of 12 erosional random wave runs (ER), 3 erosional monochromatic wave runs (EM), 7 accretionary random wave runs (AR), 3 accretionary monochromatic wave runs (AM), and 5 dune erosion random wave runs (DE). The first two numbers in the Wave Run ID "10A_60ER" indicate the major data collection test, the letter "A" indicates a particular wave condition, and "60" describes the minutes of wave action. The erosional and accretionary cases are designed based on the Dean number N,

$$N = \frac{H_b}{wT} \tag{9}$$

where w = fall speed of the sediment, and T = wave period.

Table 1. Summary of Selected Wave Runs and Input Wave and Beach Conditions (Notation is explained at the bottom of the table).

Wave Run ID	H_o m	T_p s	L_o m	n	N	H_b m	β_s	ξ	H_{b_h} M	H_{b_l} m	H_{sl_h} m	H_{sl_l} m
10A_60ER	0.78	3.0	14.0	20	6.4	0.68	0.10	0.42	0.66	0.15	0.13	0.24
10A_130ER	0.78	3.0	14.0	20	6.8	0.68	0.09	0.38	0.67	0.15	0.10	0.23
10A_270ER	0.78	3.0	14.0	20	6.9	0.68	0.10	0.42	0.65	0.16	0.10	0.24
10B_20ER	0.71	3.0	14.0	3.3	6.6	0.65	0.14	0.58	0.63	0.17	0.10	0.23
10B_60ER	0.73	3.0	14.0	3.3	6.8	0.67	0.11	0.44	0.65	0.17	0.11	0.24
10B_130ER	0.72	3.0	14.0	3.3	7.0	0.69	0.09	0.36	0.67	0.18	0.12	0.25
10E_130ER	0.69	4.5	31.6	20	4.9	0.72	0.11	0.69	0.71	0.15	0.15	0.16
10E_200ER	0.69	4.5	31.6	20	5.0	0.74	0.12	0.77	0.72	0.15	0.15	0.18
10E_270ER	0.69	4.5	31.6	20	5.1	0.76	0.09	0.58	0.74	0.15	0.16	0.20
10F_110ER	0.66	4.5	31.6	3.3	5.1	0.75	0.09	0.58	0.72	0.18	0.15	0.26
10F_130ER	0.68	4.5	31.6	3.3	5.1	0.76	0.08	0.48	0.74	0.18	0.13	0.21
10F_170ER	0.69	4.5	31.6	3.3	5.1	0.76	0.08	0.50	0.73	0.20	0.12	0.24
G0_60EM	1.05	3.0	14.0	M	10.0	1.18	0.10	0.43	1.18	0.01	0.11	0.03
G0_140EM	1.04	3.0	14.0	M	10.5	1.04	0.10	0.41	1.04	0.04	0.08	0.10
G0_210EM	1.15	3.0	14.0	M	10.8	1.07	0.09	0.39	1.07	0.04	0.11	0.02
30A_60AR	0.34	8.0	99.9	3.3	1.6	0.41	0.14	2.24	0.40	0.06	0.24	0.08
30A_130AR	0.33	8.0	99.9	3.3	1.6	0.39	0.13	2.09	0.38	0.06	0.24	0.09
30A_200AR	0.34	8.0	99.9	3.3	1.6	0.41	0.13	2.02	0.40	0.06	0.25	0.10
30C_130AR	0.31	9.0	126.4	20	1.4	0.40	0.13	2.36	0.40	0.04	0.18	0.05
30C_200AR	0.31	9.0	126.4	20	1.4	0.39	0.15	2.31	0.38	0.04	0.19	0.06
30C_270AR	0.31	9.0	126.4	20	1.4	0.39	0.15	2.60	0.38	0.04	0.20	0.06
30D_40AR	0.37	9.0	126.4	20	1.4	0.41	0.13	2.00	0.42	0.05	0.17	0.07
I0_80AM	0.60	8.0	99.9	M	2.9	0.76	0.20	2.78	0.76	0.01	0.38	0.03
I0_290AM	0.63	8.0	99.9	M	3.1	0.81	0.17	2.35	0.81	0.01	0.34	0.02
I0_590AM	0.60	8.0	99.9	M	2.7	0.72	0.12	1.64	0.73	0.01	0.25	0.03
60A_40DE	0.69	3.0	14.0	3.3	6.2	0.61	0.12	0.55	0.58	0.14	0.16	0.24
60A_60DE	0.69	3.0	14.0	3.3	6.2	0.61	0.10	0.46	0.60	0.14	0.12	0.24
60B_20DE	0.64	4.5	31.6	3.3	4.4	0.66	0.11	0.74	0.63	0.15	0.18	0.24
60B_40DE	0.63	4.5	31.6	3.3	4.4	0.66	0.11	0.76	0.62	0.16	0.18	0.25
60B_60DE	0.65	4.5	31.6	3.3	4.4	0.66	0.12	0.79	0.63	0.17	0.18	0.30

n = spectral peakedness; β_s. = beach slope defined as the slope of the section approximately 1 m landward and 1 m seaward of the shoreline; H_{b_h} = incident band wave height at the breaker line; H_{b_l} = low frequency band wave height at the breaker line; H_{sl_h} = incident band wave height at the shoreline; H_{sl_l} = low-frequency band wave height at the shoreline.

Beach Profile Change

Typically, erosion is defined as a net offshore transport of sand resulting in a loss of beach volume above the mean water line. Accretion is defined as a total net onshore transport of sand, building the beach above mean water level. As expected, a larger Dean number N resulted in erosion, and a smaller N induced accretion (Table 1).

Significant profile change occurred during the first erosional wave run case, 10A, over the monotonic initial profile (Eq. 8). Substantial shoreline recession occurred along with the development of an offshore bar (Fig. 2A). Initially, the foreshore exhibited a convex shape while the end profile was concave. The 270-min profile was substantially steeper near the shoreline than the initial profile. A bar formed after 60 min of wave action.

After 270 min, the bar moved 4 m further offshore. The maximum beach-face recession occurred at the +0.37 m contour line. The subsequent wave runs were conducted over the barred beach. The beach-profile changes are detectable, but much more subtle. Fig. 2B shows an example of shoreline accretion and onshore bar movement.

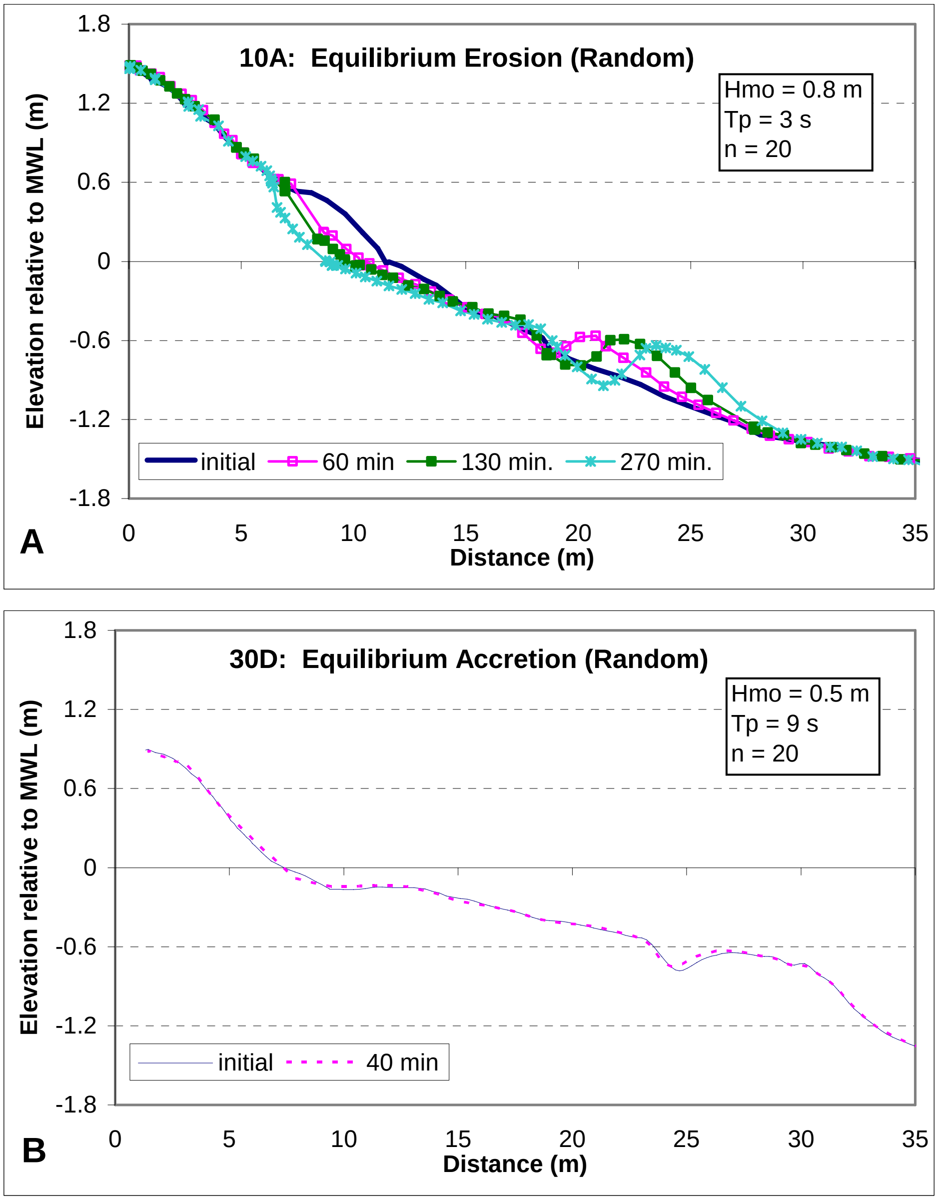

Fig. 2. (A) Bar development over monotonic equilibrium beach-profile, and (B) profile developed under accretionary random waves

In some of the erosional wave runs, a scarp developed (Fig 3A). Beach slope immediately seaward of the scarp tends to be steeper than on a non-scarped beach. The nearly vertical scarp had significant influence on the wave runup, limiting the swash uprush abruptly. Monochromatic waves tend to create erratic and undulating profiles (Fig 3B), in contrast to the smooth profiles under random waves, likely because of wave reflection. The erratic profile evolution did not seem to approach a stable equilibrium

shape. In addition, the profile shape developed under monochromatic waves does not represent profiles typically measured in the field (Wang and Davis 1998).

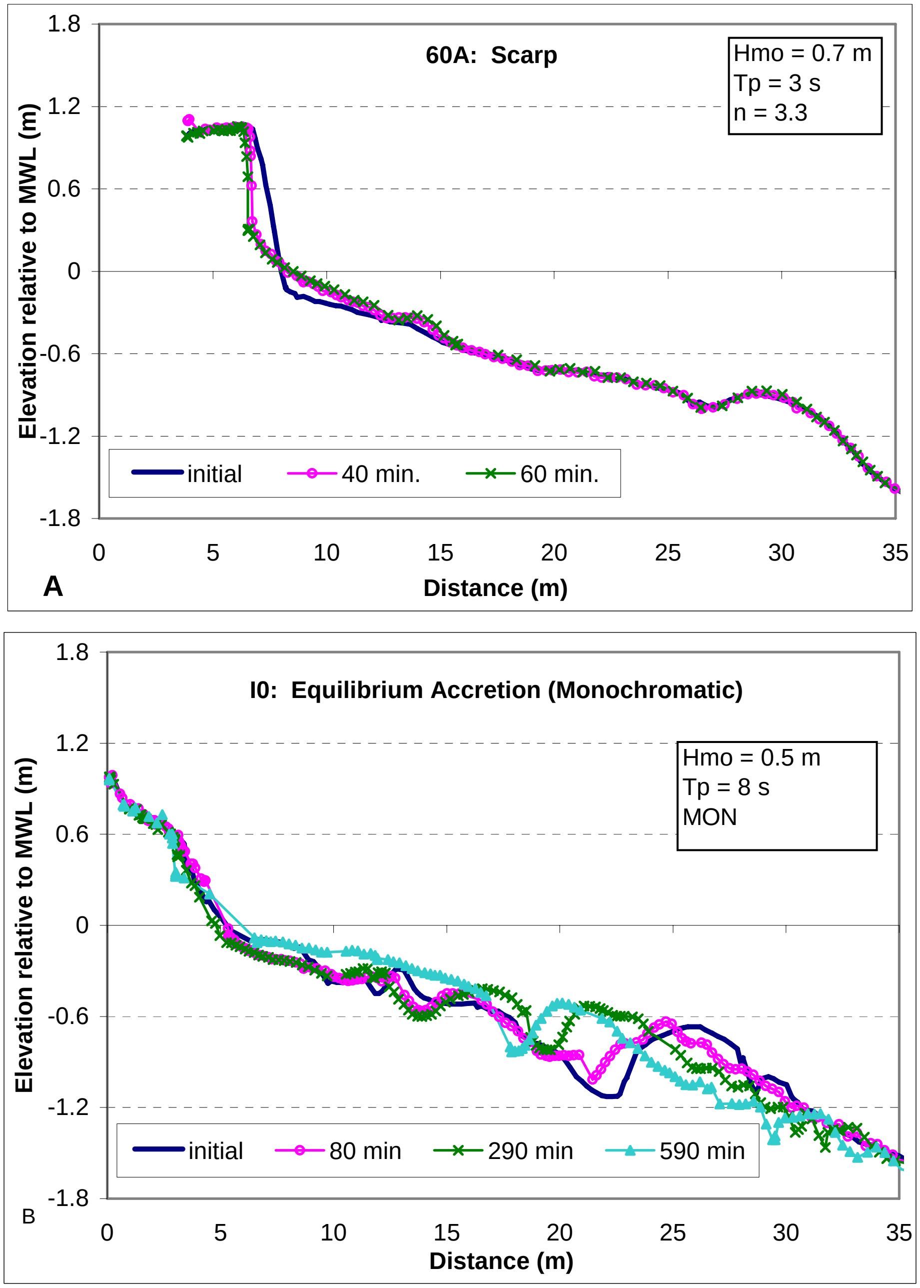

Fig. 3. (A) Scarp development, and (B) beach profiles under monochromatic waves.

The time-series of beach profiles (e.g., Figs. 2 and 3) were examined to determine the trend of erosion or accretion, and the upper and lower limits of change during each wave run (Table 2). Table 2 also summarizes the measured and predicted limits of wave runup, discussed in the following section. For the scarped cases, the upper limit of profile change was at the top of the scarp. Thus, it is controlled by the height of the beach berm or dune, and does not directly represent the extent of wave action. In

Table 2, the listed upper limit used for the scarped cases was the elevation of the scarp toe. The purpose is to link toe erosion or accretion to the wave condition.

For the studied 30 wave runs, the incident breaking wave height ranged from 0.39 to 1.18 m (Table 2). The measured upper limit of profile change, including the scarped cases, ranged from 0.27 to 0.70 m. The lower limit of beach change ranged from 0.65 to 1.61 m. Relationship between the profile change and wave condition is discussed in the following sections.

Table 2. Summary of Upper and Lower Limit of Beach Changes and Measured and Predicted Wave Runup Equations.

Wave Run ID	H_b m	R_{max} m	UL m	LL *m*	Scarp	Eq 4 m	Eq 6 M	Eq 7 m	Eq 10 m
10A_60ER	0.68	0.60	0.66	1.29	No	0.59	0.43	0.31	0.68
10A_130ER	0.68	0.60	0.66	1.29	No	0.59	0.40	0.29	0.68
10A_270ER	0.68	0.70	0.66	1.29	No	0.59	0.43	0.31	0.68
10B_20ER	0.65	0.33	0.67	1.35	No	0.54	0.49	0.38	0.65
10B_60ER	0.67	0.70	0.67	1.35	No	0.55	0.42	0.31	0.67
10B_130ER	0.69	0.64	0.67	1.35	No	0.55	0.36	0.26	0.69
10E_130ER	0.72	0.77	0.74	1.52	No	0.52	0.53	0.46	0.72
10E_200ER	0.74	0.78	0.84	1.52	No	0.52	0.58	0.51	0.74
10E_270ER	0.76	0.45	0.84	1.52	No	0.52	0.47	0.41	0.76
10F_110ER	0.75	0.40	0.43	1.52	Yes	0.50	0.45	0.40	0.75
10F_130ER	0.76	0.38	0.42	1.52	Yes	0.52	0.41	0.36	0.76
10F_170ER	0.76	0.45	0.48	1.52	Yes	0.52	0.42	0.36	0.76
G0_60EM	1.18	0.28	0.38	1.61	No	0.78	0.58	0.36	1.18
G0_140EM	1.04	0.18	0.25	1.61	Yes	0.77	0.56	0.35	1.04
G0_210EM	1.07	0.32	0.27	1.61	Yes	0.85	0.60	0.35	1.07
30A_60AR	0.41	0.41	0.31	1.36	No	0.28	0.70	0.72	0.41
30A_130AR	0.39	0.43	0.31	1.36	No	0.27	0.64	0.66	0.39
30A_200AR	0.41	0.42	0.31	1.36	No	0.28	0.64	0.66	0.41
30C_130AR	0.40	0.40	0.39	1.01	No	0.25	0.67	0.73	0.40
30C_200AR	0.39	0.42	0.42	1.01	No	0.25	0.73	0.79	0.39
30C_270AR	0.39	0.42	0.42	1.01	No	0.25	0.73	0.79	0.39
30D_40AR	0.41	0.23	0.43	0.65	No	0.30	0.69	0.76	0.42
I0_80AM	0.76	0.27	0.46	1.82	No	0.46	1.51	1.27	0.76
I0_290AM	0.81	0.16	0.53	1.82	No	0.48	1.35	1.12	0.81
I0_590AM	0.72	0.35	0.53	1.82	Yes	0.46	0.94	0.80	0.72
60A_40DE	0.61	0.17	0.28	1.16	Yes	0.52	0.45	0.34	0.61
60A_60DE	0.61	0.17	0.28	1.16	Yes	0.52	0.40	0.29	0.61
60B_20DE	0.66	0.16	0.38	0.99	Yes	0.49	0.52	0.45	0.66
60B_40DE	0.66	0.16	0.38	0.99	Yes	0.48	0.52	0.45	0.66
60B_60DE	0.66	0.17	0.38	0.99	yes	0.5	0.56	0.48	0.66

$\boldsymbol{R_{max}}$ = measured maximum wave runup; **UL, LL** = upper and lower limit of beach change, respectively.

Wave Runup

Measured and predicted wave runup is summarized in Table 2. Three examples, a random wave run without scarp (Fig. 4A), a random case with scarp (Fig. 4B), and a monochromatic case (Fig. 4C), are given. The non-scarp random wave cases are most compatible with existing field studies. The measured wave runup for the scarp cases are much lower than that for the non-scarp cases, apparently limited by the steep scarp. Wave runup generated by monochromatic waves is also much smaller than that by random waves with similar statistical wave height and period.

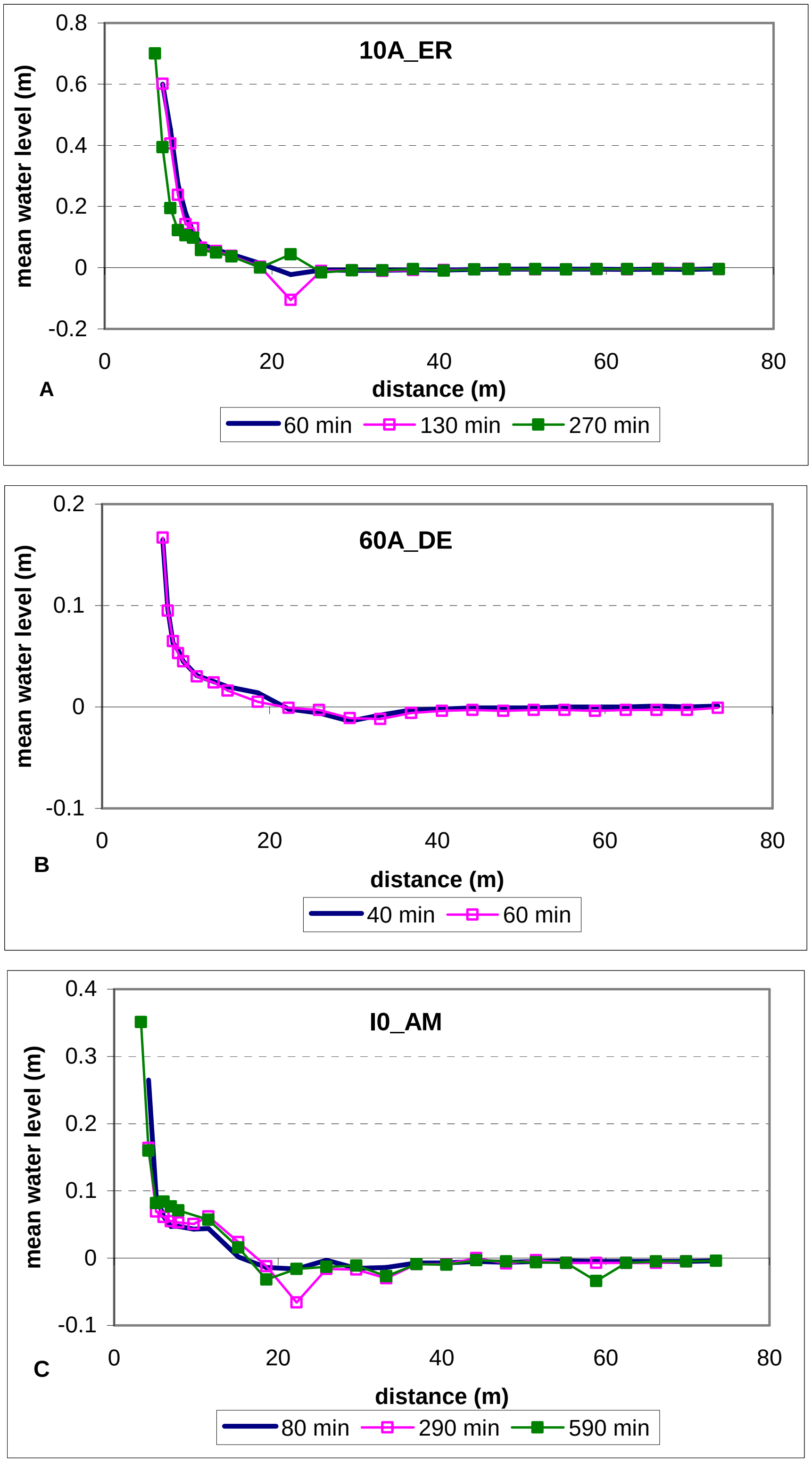

Fig. 4. Examples of wave runup under random wave (A), over a scarped beach, and (B) under monochromatic waves (C).

A direct relationship between the measured runup height on non-scarp beach and breaker height as developed with the SUPERTANK data is:

$$R_{\max} = 1.0\ H_b \tag{10}$$

Compared to the various existing empirical formulas, Eq. (10) adopts the approach introduced by Guza and Thornton (1982) and is simple, involving only the breaking wave height. Except for three wave runs, the observed wave runup equals the breaking wave height. Eq. (10) reproduced the measured values closely (Fig. 5). Agreement between measured and predicted values was reduced by including the surf similarity parameter, ξ. Eqs. (6) and (7) under-predicted the measured wave runup significantly for the erosional cases with steep waves, while over-predicted for accretionary cases. Loss of predictive capability is caused by the substantially greater ξ for the gentle long-period accretionary waves than the steep short-period erosional waves (Table 1).

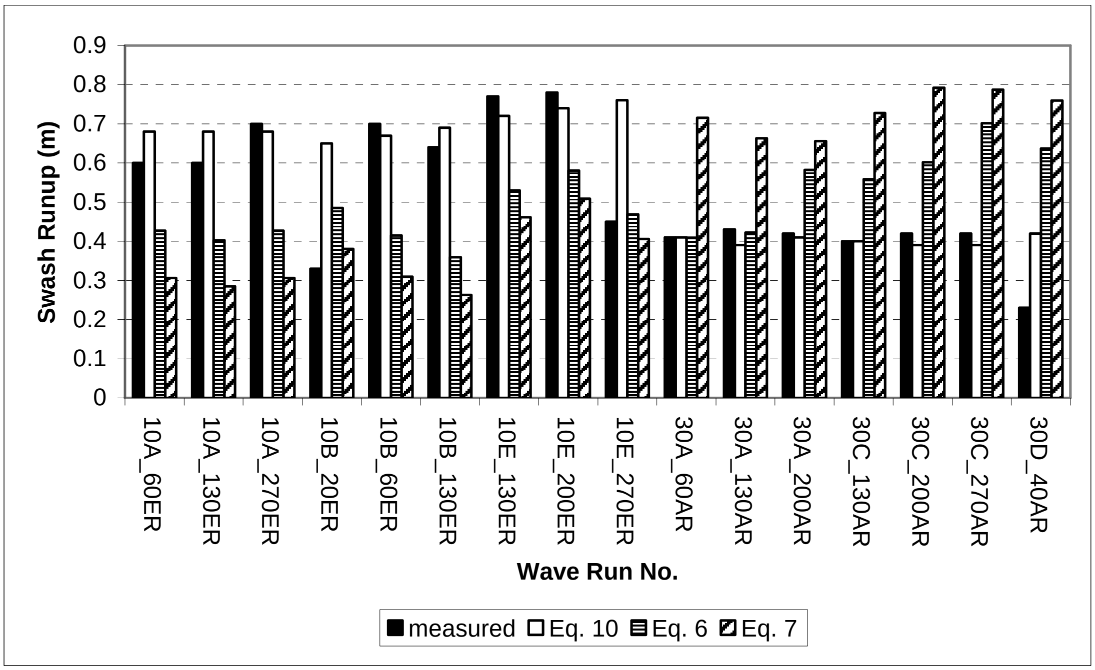

Fig. 5. Comparison of measured and predicted wave runup by three equations.

Douglass (1992) re-analyzed the Holman (1986) data set and found no correlation between runup and beach-face slope. He further argued that beach slope is a dependent variable that is free to respond to the incident wave energy and should not be included in a runup prediction. In practice, beach face slope is a difficult parameter to define and determine. Except for Stockdon et al. (2006), a clear definition of beach slope is not given in most studies. However, the Stockdon et al. definition of beach slope is difficult to utilize. In the present paper, the slope is defined over that portion of the beach extending roughly 1 m landward and seaward from the shoreline. The accretionary cases tend to have greater slope, 0.13 to 0.20, whereas the erosional case have slopes of 0.08 to 0.14 (Table 1). Examination of Fig. 3 indicates that the beach face is curved instead of planar. Therefore, substantially different beach slopes can be obtained by imposing different definitions. Including the beach slope thus adds ambiguity in applying the

empirical formulas. Determining offshore wave height may also cause uncertainty. In most field studies, the offshore wave height was taken to be that measured at a wave gage in the study area. Similarly, here it is taken as that from the offshore-most gauge. Under extreme storm conditions, estimating the offshore wave height may not be straightforward (Wang et al. 2006).

One of the first empirical formulas (Eq. 4) predicting the significant runup height R was developed by Guza and Thornton (1982) based on field measurements. As discussed previously, wave runup height measured here is expected to approximate the maximum runup R_{max}. If a Raleigh distribution of wave height is assumed, the maximum wave height should be 1.4 times the significant height. Multiplying the proportional constant of 0.71 in Eq. (4) by 1.4 yields approximately 1, which is the empirical coefficient obtained here. Therefore, the simple formula found in this study agrees with the form found by Guza and Thornton (1982).

It has been documented in many field studies performed on gently sloping beach that the swash motion and, therefore runup, is dominated by low-frequency wave energy. Typically, the low-frequency energy is defined as that carried by the wave components exceeding twice the incident peak period. The magnitudes of the incident and low-frequency energy are compared at the breaker line, H_{b_h} and H_{b_l}, and at shoreline, H_{sl_h} and H_{sl_l} (Table 1). For monochromatic waves, little low-frequency energy was measured at the breaker line and the shoreline. Lack of low-frequency modulation may explain the relatively low swash runup measured during the regular wave cases (Table 2).

For the random wave cases, energy from the incident band dominates at the breaker line (Table 1). The incident-band energy decreased significantly at the shoreline, whereas the low-frequency energy increased. This is readily apparent for the short-period steep erosional waves, where low-frequency energy dominated at the shoreline. The wave spectral peakedness n does not seem to have great influence on this trend. For the longer period gentle accretionary waves, the decrease of incident-band energy was not as rapid and low-frequency energy did not become the dominant band at the shoreline (Table 1). The low-frequency component is defined dynamically here as exceeding twice the incident peak period. For the erosional waves, the low-frequency component starts at 6 or 9 s, whereas for the longer accretionary waves, it starts at 16 or 18 s.

Relationship between Wave Runup and Limit of Beach-Profile Change

A major goal of studying the maximum wave runup is to predict the upper limit of beach changes. Knowledge of the maximum runup is valuable in evaluating the limit of storm-induced beach or dune erosion. For the random wave runs without scarps, the measured upper limit of beach-profile change roughly equals the measured wave runup (Fig. 6). Thus, the wave runup, predictable using significant breaking wave height, can be directly used to calculate the upper limit of beach erosion. For cases with beach or dune scarps, the upper limit of the beach change is controlled by the elevation of the back-beach berm or dune (Fig. 3A). Once a scarp forms, the overlying sediment will eventually collapse under gravity and cause significant change above the upward limit of

water excursion. The measured wave runup is subdued by the nearly vertical scarp and the steep beach slope directly seaward of the scarp; and it cannot be predicted by known empirical formulas.
Beach-profile change under monochromatic waves differs greatly from that under the more realistic random waves. Both wave runup and upper limit of beach-profile change are significantly smaller than those under random waves with similar statistical wave height and period. Findings from laboratory monochromatic movable-bed studies are not directly applicable to field conditions, as also discussed by Wang and Kraus (2005).

Although not a focus of this study, the lower limit of beach changes was also measured and is listed in Table 2. Typically, the lower limit of beach-profile change is 1.5 to 3 times the significant breaking wave height. Longer period waves seem to influence beach change in deeper water (~ 3 times H_s), as compared to shorted period waves (~ 2 times H_s). It was beyond the scope of this paper to examine factors controlling the lower limit of the beach change.

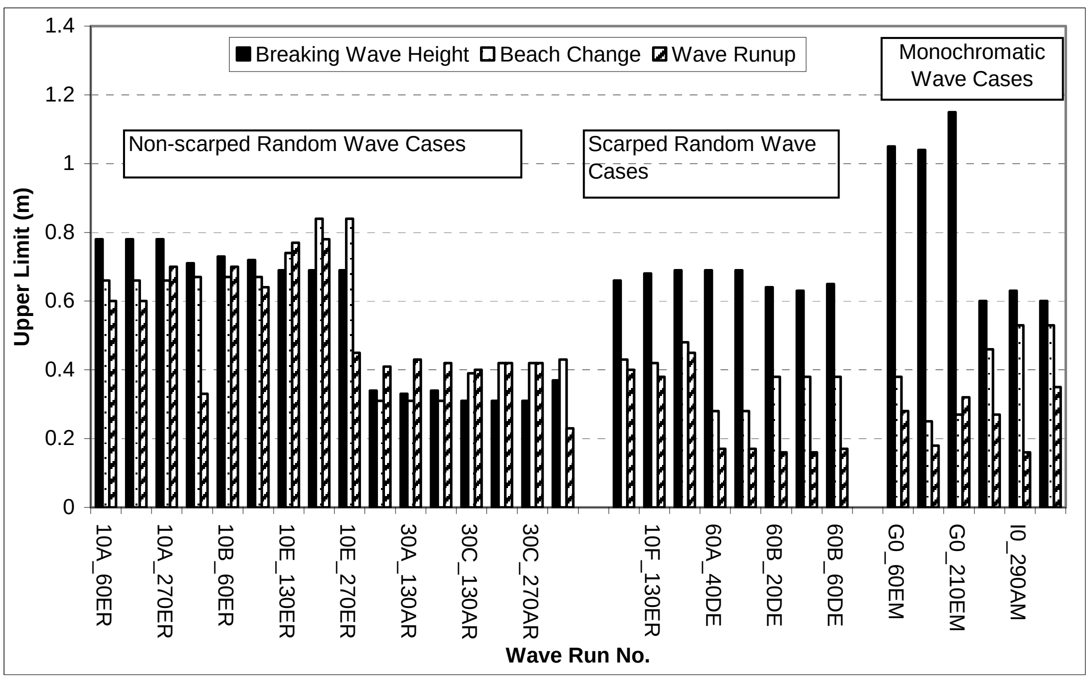

Fig. 6. Comparison of wave runup, upper limit of beach change, and breaking wave height.

CONCLUDING DISCUSSION

SUPERTANK's unique dataset was analyzed to examine the effects of elevated water level caused by wave setup and swash runup on the upper limit of beach and dune change. Thirty SUPERTANK wave runs were investigated. The investigated runs demonstrate that the Dean Number is a reliable indicator for predicting the general trend of beach erosion and accretion. In fact, the SUPERTANK experiments were designed in this way (Kraus and Smith 1992).

The SUPERTANK data indicate that the vertical extent of wave runup above mean water

level on a non-scarped beach is approximately equal to the significant breaking wave height. A simple empirical formula for predicting the maximum wave runup, *Rmax*: $R_{\max} = 1.0\, H_b$, is therefore developed. This formula agrees with the original runup formula concept of Guza and Thornton (1982). The reliability of the calculated wave runup decreased, as compared to measured values, by including the surf similarity parameter. An exception to the direct relationship between breaking wave height and runup concerns dune or beach scarping. The steep scarp substantially limits the uprush of swash motion, resulting in a much reduced maximum level, as compared with the non-scarping situation. For monochromatic waves, the measured wave runup is much smaller than the breaking wave height. The lack of low-frequency modulation limits the wave runup for monochromatic waves.

Based on the SUPERTANK experiments, the upper limit of beach-profile change was found to be approximately equal to the maximum vertical excursion of swash runup. Therefore, the limit of swash runup can serve as an estimate of the landward limit of beach change. Physical situations that are exceptions to this direct relationship are those with beach or dune scarping. For the scarping cases, the upper limit of beach change is much higher than the maximum swash runup and is controlled by the elevation of backbeach/berm or dune.

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